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A PC-based control and data acquisition for X-ray reflection measurements

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Abstract : Recently, an 18 kW rotating anode X-ray generator has been installed in our laboratory for setting up an X-ray Standing Wave (XSW) experimental facility. As an early stage of development we designed and fabricated simple tilting stages to measure reflections from single crystals. We have used a personal computer with add-on boards for the control of the incident angle and the data acquisition. To demonstrate the functioning of this setup we show Bragg diffraction measurement on an asymmetrically cut S(111) dislocation-free single crystal, which will be used later as a monochromator for preparing a plane wave beam for XSW experiments. We also present the determination of the misorientation direction and angle of a vicinal Si(111) surface.

Keywords : Single crystal diffraction, asymmetric reflection, vicinal surface, PC-based control

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1. Introduction

X-ray diffraction is a common technique to characterize crystal structure. One needs a monochromatized X-ray beam for this purpose. For a sealed tube or a rotating anode X-ray source, generally, for powder diffraction analysis proper filters are used to absorb the characteristic K_β X-rays. In a sense, it works as a monochromator providing mainly the characteristic K_α X-rays. For synchrotron radiation, which comprises a continuous energy spectrum, crystal monochromators are routinely used to select X-ray photons of required energy within a narrow energy band. Some experiments require a plane wave incident X-ray beam. Besides monochromatization, a good collimation of the incident beam is necessary for a reasonable approximation to a plane wave. Soller slits are often used for collimation. However, the collimation obtained with soller slits is not good enough for some experiments. In this situation, the natural (angular) width of reflection from a dislocation-free

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(monochromator) crystal and its specific geometry is used to prepare an extremely collimated beam. A short description of this will be given later.

In this paper, we present the instrumentation and a personal-computer based control and data acquisition for X-ray reflection measurements. We demonstrate the functioning of this system with the measurement of reflection of X-rays from an asymmetrically cut Si(111) single crystal. Utilising some aspects of asymmetric reflection, we present the determination of the misorientation angle and direction of a vicinal surface.

2. Instrumentation

An 18 kW (RIGAKU 300 VE) rotating anode (Mo) X-ray generator has recently been installed in our laboratory. We are setting up the X-ray Standing Wave (XSW) technique [1] with this X-ray source. The first step in developing such a facility is the vibration isolation stage for the total setup including the X-ray unit. This has been done by making the base of the set-up (along with the X-ray unit) much more massive than the rest of the place. The X-ray unit has been placed on a solid concrete block ($1.5 \times 1.5 \times 0.3$ m^3) which has been embedded in the foundation of the building but isolated from the rest of the building by using vibration isolation pads around and below the concrete block.

The XSW technique is based on the dynamical theory of X-ray diffraction. The dynamical theory uses a plane wave incident beam on a large perfect crystal. In order to generate this plane wave we use an asymmetrically cut monochromator crystal where the asymmetry angle is slightly smaller than the Bragg angle. The X-ray unit has two line and two point sources. We have used one line focus (effective focus : 0.05×10 mm^2) for the present study. Our set-up will be mainly used for single crystal surface and interface studies. In this situation, one needs to expose a larger surface area of the sample to the X-ray beam. Hence, a point beam is not suitable. Two tilt stages have been designed and fabricated. One for the monochromator stage and the other for the sample stage. A slit system has been fabricated. This is used before the monochromator. The tilt angle is changed by using a micrometer head, which is coupled with a stepper motor. This arrangement gives the minimum angle to be 0.003° for each step. We can decrease this minimum angle further by increasing the arm length of the tilt stage.

The schematic experimental set-up is shown in Figure 1. We have fabricated the stepper motor driver unit in Tata Institute of Fundamental Research, Bombay. This unit can drive upto 5 stepper motors [2]. The input signals (TTL pulses) to the driving unit can be generated either from a microprocessor or from a PC. Here, in our experiment, the signals are generated from an add-on board, PCL–208, supplied by Dynalog Micro Systems [3], in a PC (IBM compatible PC/AT 386). This add-on board has an Analog to Digital Converter (ADC) and two Digital to Analog Converters (DAC) along with 16 In/Out (TTL pulse) channels. We have used five of these In/Out channels for the stepper motor driver. The sequence of the TTL pulses can be programmed so that the stepper motor moves either in forward or reverse direction. Each step of the stepper motor corresponds to 1.8°. The stepper motor in turn, rotates the micrometer head (Figure 1) which pushes the monochromator (or the sample) arm. The tilt angle depends on the arm length and the pitch of the micrometer. The variation of the incident angle and the data acquisition are done with the same PC mentioned above. The reflected X-ray beam is detected with a BaF_2 scintillation detector. This detector is mounted

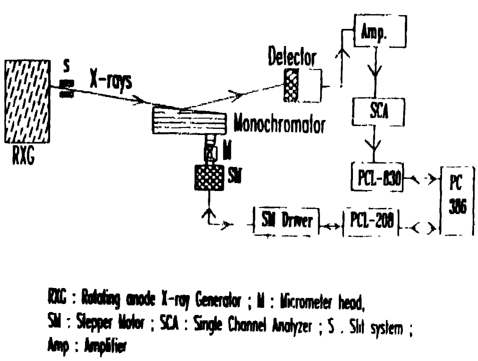

Figure 1. The schematic experimental set-up for reflection measurements.

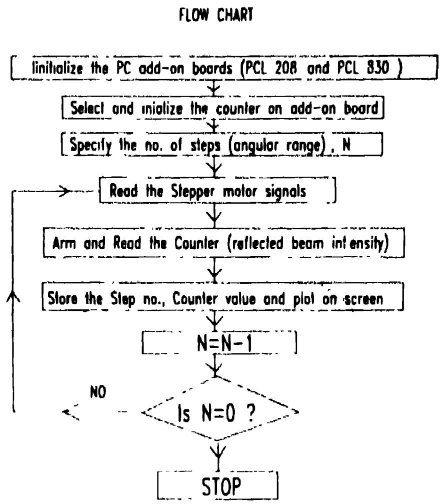

Figure 2. Flow-chart of the control and data acquisition programme

on a stage which can be moved up or down (vertically). Even though the X-rays give low pulse height with BaF_2 detector (2.5 cm thick crystal; the amplified (× 1000) X-ray pulse height is a few hundred millivolts), this detector is good enough to find the reflection from a crystal. The amplified signal from the main amplifier is fed to a Single Channel Analyser (SCA) and the output is given to PCL–830, another add-on board (also from Dynalog Micro Systems) in the PC PCL–830 two powerful counters (AMD 9513 counters). Each counter has five independent 16-bit programmable counters. One of these counters is used to count pulses coming from the SCA. There is one independent counter (Intel 8254) available with the PCL–208 add-on board. But, to work with more than 16-bit count value, it is not possible to use this counter. Using the counters from the AMD 9513 counter board, it is possible to concatenate two counters (or more) and get a maximum count equivalent to 32 bits (or higher). A programme has been written in GWBASIC which changes the incident angle and stays there for a predetermined period (using PCL–208) and collects the reflected beam intensity with the counter (using PCL–830). This programme has been written using the library functions supplied for the counter. The angular position and the counter output are plotted on the monitor (Super VGA colour monitor) in real-time mode of operation. The flow-chart of the total programme is shown in Figure 2 and the programme is given in appendix A.

3. Results

3.1. Automatic data collection and real time display :

Figure 3 shows the reflection from an asymmetrically cut Si(111) single crystal as collected and displayed on the monitor in real time. Here we can clearly see the separation between Mo K_α and Mo K_β X-rays. Even though our reflecting crystal is asymmetric (Figure 4(b)), it has

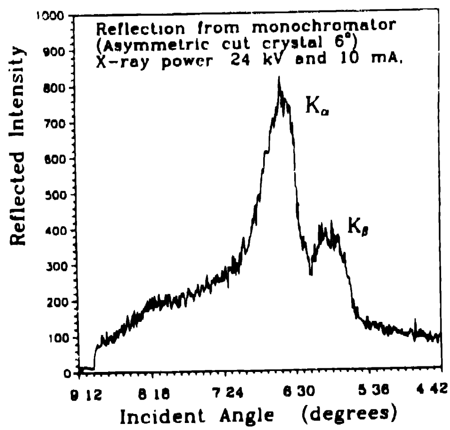

Figure 3. Reflection from the monochromator crystal, where both Mo K_α and K_β X-rays satisfy the Bragg condition, *i.e.*, when the beam is incident on the symmetric part of the asymmetrically cut monochromator crystal (confer Figure 4(b)). When the beam is incident on the asymmetrically cut surface, the K_β part of the spectrum is absent in the reflected beam. See the text for details

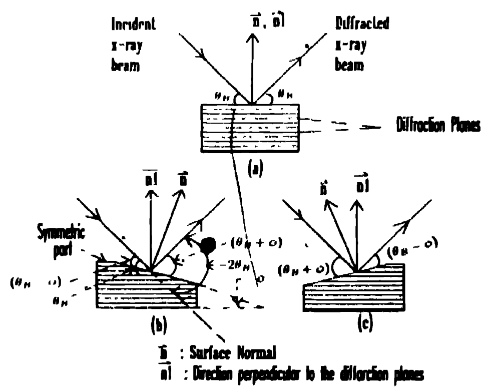

Figure 4. Diffraction geometries (a) symmetrically cut (surface parallel to the diffraction planes) crystal, (b) and (c) asymmetrically cut crystal (angle between the surface and the diffraction planes is ϕ). The configuration in (c) is obtained by rotating the crystal in (b) by 180° about $\vec{nl}$.

a small symmetric part for the identification of the (111) orientation. The incident beam has been allowed to fall on this symmetric part to get the spectrum shown in Figure 3. If the beam is restricted to be incident on the asymmetrically cut surface, the K_β line will be automatically suppressed as the diffraction condition for the K_β line cannot be satisfied.

For the (111) reflection from a silicon crystal, the planar spacing is d = 3.135 Å. For Mo K_β X-rays, λ = 0.632 Å. Applying Bragg condition

$$2d\sin(\theta_B) = n\lambda \tag{1}$$

one gets the Bragg angle θ_B = 5.785° (for n = 1). Here we will restrict our discussions to the Bragg case or Bragg geometry, *i.e.*, where the X-ray beam enters and exits through the same face of the crystal. (In the Laue case the beam enters and exits through different faces). For the crystal we have used, the asymmetry angle ϕ is 6°, and thus the smallest incident angle, which corresponds to the beam parallel to the crystal surface, gives an angle of 6° between the incident beam and the diffraction planes (confer Figure 4(b)). Thus the Bragg condition for the K_β X-rays cannot be satisfied in this geometry.

For the monochromator used in an XSW experiment, the incident beam is allowed to fall on the asymmetrically cut surface in the configuration shown in Figure 4(b). The detailed properties of an asymmetrically cut perfect crystal can be obtained from an analysis of the *dispersion surfaces* in the dynamical theory [4]. Although our intention here is not to give the details, we briefly describe some special aspects of an asymmetrically-cut monochromator crystal. The K_α X-ray beam has two components : $K_{\alpha 1}$ and $K_{\alpha 2}$. These can be separated with proper slits in the incident and the diffracted beams. The advantage of the asymmetrically cut crystal lies in its use as a collimator in addition to its monochromatization property. When the characteristic X-rays are Bragg diffracted, the X-rays ranging in energy over the natural line width ΔE of the selected line are simultaneously diffracted. The spread in Bragg angle corresponding to ΔE can be obtained by differentiating eq (1) :

$$d\theta/dE \;=\; -(E\cot\theta)^{-} \tag{2}$$

where E is the energy of the X-ray photons. For the diffraction of molybdenum $K_{\alpha 1}$ X-rays from silicon (111) planes

E = 17.489 keV, ΔE = 6.8 eV, d = 3.135 Å, θ_B = 6.493° and hence

$\Delta\theta$ = 44 μrad (≈ 9 arc sec).

From the dynamical theory of X-ray diffraction the angular acceptance width of the diffracting crystal is given by

$$W_{in} \;=\; 2|P|\; F'_H \Gamma /\; |b|^{1/2}\; \sin 2\theta_B \tag{3}$$

where F'_H is the real part of the structure factor, b is the asymmetry parameter defined by

$$b \;=\; -\sin(\theta_B \;-\; \phi)/\sin(\theta_B \;+\; \phi), \tag{4}$$

ϕ being the asymmetry angle (angle between the surface and the diffraction planes as shown in Figure 4(b)) of the diffracting crystal. In eq. (3), $P = 1$ for σ-polarization and $P = \cos(2\theta_B)$ for π-polarization of the incident beam and $\Gamma = r_e\lambda^2/\pi V$; r_e is the classical electron radius and V is the volume of the unit cell of the crystal.

The angular width of the exit beam is given by

$$W_{out} \;=\; |b| W_{in} \,. \tag{5}$$

For a symmetrically cut crystal $\phi = 0$, and in the Bragg case $b = -1$. Hence,

$$W_{out} \;=\; W_{in} \,.$$

However, for an asymmetrically cut crystal, for the configuration shown in Figure 4(b),

$$W_{out} \;<\; W_{in}$$

and an exit beam with reduced angular divergence (collimation effect) is produced.

For Mo $K_{\alpha 1}$ X-rays and Si(111) reflection, using eqs. (3), (4) and (5), and for σ-polarization we obtain the following values.

$$W_{\mathrm{in}}\ (\text{symmetric}) = 15.12\ \mu\text{rad.}$$

$$W_{\mathrm{out}}\ (\text{symmetric}) = 15.12\ \mu\text{rad}$$

$$W_{\mathrm{in}}\ (\text{asymmetric}) = 75.70\ \mu\text{rad.}$$

$$W_{\mathrm{out}}\ (\text{asymmetric}) = 3.01\ \mu\text{rad.}$$

Thus for this asymmetric crystal used in the geometry shown in Figure 4(b), the acceptance angle is 75.7 μrad while the exit beam after Bragg diffraction has an angular divergence of 3.01 μrad—an extremely well collimated beam. The collimated beam obtained this way is used as an incident beam in XSW experiments.

3.2. Determination of misoreintation direction of a vicinal Si(111) surface :

We also used the simple set-up described here to solve a problem we came across in our research in surface physics. In our study of growth of epitaxial gold silicide islands on bromine-passivated Si(111) substrate we observed the islands to grow in the shape of equilateral triangles up to a critical size beyond which the symmetry of the structure is broken, resulting in a shape transition from triangle to trapezium [5]. We have observed that the elongated islands grow only along one preferential direction instead of growing along three equivalent directions on the Si(111) substrate. This has been attributed to the vicinality of the substrate surface [6]. A crystal surface slightly misoriented from an *(hkl)* Miller plane is called a vicinal surface. A vicinal Si(111) surface has single-layer and triple-layer steps and step bunches [7]. Certain features are enhanced depending on the misorientation direction of the surface-normal ($\boldsymbol{n}$). The growth and orientation of epitaxial layers on a vicinal surface is influenced by the step direction and step density [8], which is determined by the miscut angle (angle between $[h\ k\ l]$ and $\boldsymbol{n}$). For our study of epitaxial gold silicide growth we used commercially available Si(111) wafer which was supposed to have a $(4 \pm 0.5)°$ miscut. However, the direction of the surface normal was not known. Only a small cut on the wafer identified the $[1\ \bar{1}\ 0]$ direction. In this section, we show how we determined the orientation of the surface normal ($\boldsymbol{n}$). This information was essential to establish that the alignment of the elongated gold silicide islands was along the Si(111) surface steps [6].

Figure 4 gives a clear picture of how simple the determination of misoreination direction is. The configuration for Bragg diffraction shown in Figure 4(a) is for a symmetrical crystal and those in Figure 4(b) and Figure 4(c) are for the asymmetric case. The Bragg angle for Mo $K_{\alpha 1}$ X-rays and Si(111) reflection is 6.493°. For the configuration shown in Figure 4(b), in order to obtain a diffracted beam, *i.e.*, to satisfy the Bragg condition, the angle between the incident X-ray beam and the crystal surface has to be $\theta_B - \phi$. This angle is easily measured by initially aligning the incident beam with the crystal surface, then placing the detector at a scattering angle of $2\theta_B$ and increasing the angle of incidence to obtain the reflection. Say this measured angle of incidence is θ_1. Thus, $\theta_B - \phi = \theta_1$. When the crystal is rotated by 180° to obtain the configuration shown in Figure 4(c), an angle of incidence equal to $\theta_B + \phi$ is required to obtain the diffracted beam, *i.e.*, to satisfy the diffraction condition. Say, the measured angle of incidence is now θ_2. That is, $\theta_B + \phi = \theta_2$. Then one obtains $\phi = (\theta_2 - \theta_1)/2$. Thus, the unknown asymmetry angle is determined. This also establishes where the surface-normal (***n***) lies with respect to ***n*** 1. When the crystal is rotated through 90° or 270° about ***n*** 1 from the configuration shown in Figure 4(b), there is no asymmetry involved and one obtains diffraction for an incident angle equal to θ_B.

The Si(111) substrate for which the misoreintation direction was to be found, was loaded and the reflected beam intensity was measured as a function of the incident angle. The misorientation was expected to be towards any of the four azimuthal directions : $[1\ \bar{1}\ 0]$, $[\bar{1}\ 1\ 0]$, $[1\ 1\ \bar{2}]$ or $[\bar{1}\ \bar{1}\ 2]$ (Figure 5). Initially, we knew the $[1\ \bar{1}\ 0]$ direction on the sample. When the incident beam was in the plane defined by $[1\ \bar{1}\ 0]$, $[1\ 1\ 1]$ and $[\bar{1}\ 1\ 0]$ directions and either between $[1\ \bar{1}\ 0]$ and $[1\ 1\ 1]$ or $[\bar{1}\ 1\ 0]$ and $[1\ 1\ 1]$ the angles of

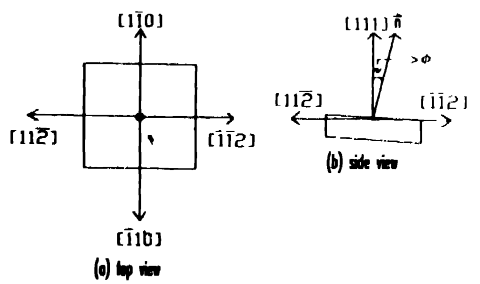

Figure 5. The crystallographic directions and the surface normal of the silicon wafer (a) $[1 1 1]$ direction is outward perpendicular to the plane of the paper. (b) The misorientation of the surface normal, as determined, is towards the $[\bar{1}\ \bar{1}\ 2]$ azimuthal direction

incidence for obtaining a diffracted beam were the same and equal to the Bragg angle (θ_B = 6.49°). Hence, there is no misorientation of the surface normal (***n***) towards $[1\ \bar{1}\ 0]$ or $[\bar{1}\ 1\ 0]$ direction. But when the incident beam was in the plane defined by $[\bar{1}\ \bar{1}\ 2]$, $[1\ 1\ 1]$ and $[1\ 1\ \bar{2}]$ directions, θ_1 and θ_2 values were different and the asymmetry angle ϕ was determined to be 3.96° ± 0.09°. The larger angle θ_2 was obtained when the incident beam was in the quadrant defined by the $[1\ 1\ 1]$ and $[\bar{1}\ \bar{1}\ 2]$ directions. This means that the surface-normal (***n***) was misoriented towards $[\bar{1}\ \bar{1}\ 2]$ direction (Figure 5). This information was not given by the supplier of the silicon wafer. The miscut angle mentioned by the supplier was 4.0° ± 0.5°. The high precision of our angle determination is also evident here.

4. Present status of the X-ray standing wave facility

Recently a four-circle diffractometer has been installed with the X-ray unit. Besides this, there is one large goniometer head which is driven by four dc motors (one motor for each degree of freedom : x- and y-motions and two tilting directions). This goniometer head is now used for the monochromator crystal. A simple circuit has been designed and used for switching the dc motor power on or off by using a bit pattern generated by the PC. A position read-back arrangement for this unit (by using a potentiometer in contact with the dc motor shaft) has been fabricated. The monochromator crystal can be set at a desired position (x, y or angle) using a control program. We have separated $K_{\alpha 1}$ and $K_{\alpha 2}$ components of K_α by using fine slits in the incident and the reflected beam. The monochromatized beam falls on the second crystal, which is mounted on a microgoniometer. The microgoniometer is attached to the diffractometer as a sample holder. Using the stepper motor (5-phase stepper motor which drives the arms of the 4-circle diffractometer unit), we bring the second crystal to the Bragg condition. This motion has already been programmed and controlled with a personal computer (the same PC described before) *via* an IEEE interface. This completes the set-up for the usual rocking curve or X-ray reflectivity measurements. The heart of the XSW technique is the microgoniometer and achieving the micro angular sweep with it. For an XSW experiment a angular precision better than 0.05 arc sec (~ 10^{-5} deg) is necessary. This is obtained utilising the tiny expansion of a piezoelectric crystal upon application of a high voltage and converting this linear displacement into angular displacement through a mechanical coupling *via* a high precision torsion bearing (flexural pivot). The microgoniometer incorporates these components and performs this job. It has a pair of capacitor plates for sensing the piezo displacement. The electronic module for the measurement of displacement has been fabricated in the Indira Gandhi Center for Atomic Research, Kalpakkam and is currently being tested. The microgoniometer has been fabricated in Bhabha Atomic Research Center, Bombay. Details of this set-up will be published later.

Acknowledgments

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APPENDIX : A

```
'10
11
12     THIS PROGRAMME GENERATES THE SIGNALS USING PCL-208 ADD-ON BOARD
13 '*  FOR THE STEPPER MOTOR AND COLLECTS THE REFLECTED X-RAY INTENSITY
14 '*  IN A COUNTER ON THE PCL-830 BOARD. THE COLLECTED DATA ARE
15       STORED IN A FILE AND ALSO DISPLAYED ON THE COLOR MONITOR AS
16     THE EXPERIMENT CONTINUES IN A REAL TIME MODE OF OPERATION.
17       THE PROGRAMME USES THE FUNCTIONS SUPPLIED BY DYNALOG MICRO
19     SYSTEMS WITH ADD-ON BOARDS
20 '**************************
22 SCREEN 9
25 CLS:KEY OFF
30 VIEW(300,50)-(600,250),,3            'SELECT THE VIEW PORT ON THE SCREEN
40 CLS
50 X1=0:Y1=0:X2=1000:Y2=35000          'X : NO OF STEPS; Y: COUNTS;
60 WINDOW (X1,Y1)-(X2,Y2)
70 LOCATE 20,50: PRINT " INCIDENT ANGLE"
75 LOCATE 11,15 :PRINT " REFLCTED INTENSITY"
77 LOCATE 4,9 : PRINT "----------------------";
80 LOCATE 8,9 : PRINT "----------------------"
85 LOCATE 4,8 :PRINT "||" : LOCATE 5,8: PRINT "||" : LOCATE 6,8
90 PRINT "||" : LOCATE 7,8:PRINT "||" : LOCATE 8,8: PRINT "||"
92 LOCATE 5,10: PRINT " COLLECTION ON!!!"
170 OPEN "O",#1, "FILE",
180 COLOR 11,1:KEY OFF:CLS
190 '**********************************************************
220 'LOAD THE PCL830.BIN DRIVER BY CONTRACTING BASIC'S WORKSPACE TO 48K
260 SG = &H4000
270 DEF SEG = SG
280 BLOAD "PCL830.BIN", 0
300 '**************************************************************
310 DIM DIO%(9),CT(6),DAT(9),CVAL(600),CVA(600),SIG(4)
330 SCREEN 9,0:CLS:COLOR 14,1
335 REM ********STEPPER MOTOR SIGNAL READING AS WELL AS SELECTING MOTOR2
340 OUT &H300 +11, 2 'SELECT THE STEMOTOR NO.2
350  DATA 10,9,5,6           'MOTOR DIRECTION
360  REM DATA 6,5,9,10
370 FOR I1=1 TO 4
380 READ SIG(I1)           ' READING THE SIGNAL VALUES; SIG(1)= 10 ETC..
390 NEXT I1
400 CLS:COLOR 13,1
401 REM ***********510 LOCATE 1,20: COLOR 14,1
560 REM 'SELECT THE CHIP0 OR CHIP 1 OF TWO 9513'S
570 DIO%(0) = 0 :FUNC%=12:FLAG%=0:CALL PCL830(FUNC%,DIO%(0),FLAG%)
580 IF FLAG% <> 0 THEN GOTO 5120
600
610 'MAKE SURE THE SELECTIN OF THE CHIP
620 FUNC%=13:CALL PCL830(FUNC%,DIO%(0),FLAG%)
630 IF FLAG% <> 0 THEN GOTO 5120
640 IF DIO%(0) <> CHIP% THEN GOTO 5120
660
670 'INTIALIZATION WITH FUNCTION 0
680 DIO%(0) = &H240  'I/O ADDRESS
690 DIO%(1) = 10     'FOUT DIVIDER RATIO OF 10
700 DIO%(2) = 11     'FOUT SOURCE = F1 (1MHZ) FOR FOUT = 10HZ
```

```
740 FUNC% = 0: CALL PCL830 (FUNC%, DIO%(0), FLAG%)
750 IF FLAG% <> 0 THEN GOTO 5120
770 '*****************************************************************
790 'NOW INITIALIZE EACH COUNTER MODE REGISTER USING FUNCTION 1
815 CTR=1
820 DIO%(0) = CTR          'COUNTER NUMBER
830 DIO%(1) = 0       'NO GATING
840 DIO%(2) = 0            'COUNT ON RISING EDGE
850 REM DIO%(3) = CTR+10 'INPUT FROM F1, F2 ETC.
851 DIO%(3)=CTR         ' INPUT FROM SOURCE1,ETC..
860 DIO%(4) = 0            'DISABLE SPECIAL GATE
870 DIO%(5) = 0            'RELOAD FROM LOAD REGISTER
880 DIO%(6) = 1            'COUNT REPETITIVELY
881 'DIO%(6) = 0            'COUNT ONCE
890 DIO%(7) = 0            'BINARY COUNT
900 DIO%(8) = 1            'COUNT UP
910 REM DIO%(9) = 5            'ACTIVE LOW TERMINAL COUNT PULSE
911 DIO%(9) = 1            ' ACTIVE HIGH TC PULSE  '
920 FUNC% = 1              'SELECT FUNCTION 1
930 CALL PCL830 (FUNC%, DIO%(0), FLAG%)   'DO CALL
940 IF FLAG% <> 0 THEN GOTO 5120
970 '************************************************
990 '--- ZERO ALL COUNTERS -----------
1000 '***************************************************************
1020 '---- RESET (ZERO) ALL COUNTERS ------------
1030 'DISARM ALL COUNTERS (STOP COUNTING) USING FUNCTION 2
1040 DIO%(0) = 6      'DISARM COUNTER
1101 DIO%(CTR)=1
1160 FUNC% = 2
1170 CALL PCL830 (FUNC%, DIO%(0), FLAG%)
1170 REM LOCATE 2,2:?"FLAG%1";FLAG%
1180 IF FLAG%<>0 THEN GOTO 5120
1200 '***************************************************************
1220 'LOAD ZERO TO ALL LOAD REGISTERS USING FUNCTION 3
1240 DIO%(0) = CTR         'COUNTER NUMBER
1250 DIO%(1) = 0               'LOAD DATA = 0
1260 FUNC% = 3                   'FUNCTION 3
1270 CALL PCL830 (FUNC%, DIO%(0), FLAG%)
1280 IF FLAG% <> 0 THEN GOTO 5120
1310 '***************************************************************
1340  DAT%(0) = 3              'LOAD AND ARM COUNTER
1351  DAT%(CTR) = 1
1360  FUNC% = 2                  'FUNCTION 2
1370  CALL PCL830 (FUNC%, DAT%(0), FLAG%)
1380  IF FLAG% <> 0 THEN GOTO 5120
2010 'READ AND DISPLAY CONTENTS OF ALL COUNTERS (DOES NOT ALTER COUNT)
2020 '----  LATCH AND READ ALL COUNTERS --------------
2030 'THIS DOES NOT INTERFERE WITH COUNTING OR CHANGE DATA
2031 'LATCH ALL COUNTERS TO HOLD REGISTERS USING FUNCTION 2
2032  REM J=1
2035  FOR J1=0 TO 150
2038  FOR J2=1 TO 4
2039  J=J2 + J1*4
2040  'PRINT "J";J
2050 DAT%(0) = 5      'LATCH TO HOLD
2061 DAT%(CTR)=1
2070 FUNC% = 2         'FUNCTION 2
2080 CALL PCL830 (FUNC%, DAT%(0), FLAG%)
2090 IF FLAG% <> 0 THEN GOTO 5120
```

```
2130 'READ EACH HOLD REGISTER AND RETURN COUNT IN CT(N) USING FUNCTION 4
2140 DIO%(0) = CTR        'SELECT COUNTER NUMBER
2151 DIO%(CTR)=1
2160 FUNC% = 4                'FUNCTION 4
2170 CALL PCL830 (FUNC%, DIO%(0), FLAG%)
2180 IF FLAG% <> 0 THEN GOTO 5120
2200 'CORRECT FOR 2'S COMPLEMENT (NEGATIVE INTEGERS)
2207 CVAL(J) = DIO%(1)  'RETURN DATA RANGE -32768 TO +32767
2210 IF CVAL(J) < 0 THEN CVAL(J) = 65536! + CVAL(J)
2215  CVA(J)=CVAL(J)-CVAL(J-1)
2350    PSET(J,CVA(J))     ' DISPLAY ON THE MONITOR
2354  PRINT  "J,CVA(J)"; J, CVA(J)   ' STORE IN A FILE
2355  PRINT #1,CVA(J)
2360 REM ****STEPPER MOTOR****
2370  REM FOR I2=1 TO 45    'I=1 GIVES 4 STEPS; HALF A ROTATION (100 STEPS)
2372  REM FOR J2=1 TO 4
2374   OUT &H300 +3, SIG(J2)        ' OUTPUT TO DIGOUT, LOWBYTE
2375  REM FOR J2=1 TO 10 : NEXT J2
2376  REM FOR J2=1 TO 4500:NEXT J2
2378  REM NEXT I2
2380 FOR I=1 TO 2000
3076 X%=2
3077 Y%=3
3078 Z-=X%+Y%
3079 NEXT I
3080 NEXT J2
3082 NEXT J1
3085 REM GOTO 1240
4100 LOCATE 24,15:COLOR 13,1
4105 PRINT"PRESS ESC TO ABORT, OTHER KEY TO CONTINUE !";
4110 A$=INKEY$:IF A$ = "" GOTO 4110
4120 IF A$=CHR$(27) THEN GOTO 4130 ELSE GOTO 400
4130 LOCATE 24,15:PRINT"RESET COUNTERS AND RESTART COUNTING ? (Y/N) ";
4140 A$=INKEY$:IF A$="" GOTO 4140
4150 REM IF A$="Y" OR A$="Y" THEN LOCATE 22,15
4151 COLOR 4,0:PRINT SPACE$(51):GOTO 320
4155 IF A$="Y" OR A$="Y" THEN GOTO 400 ELSE GOTO 4160
4160 COLOR 13,1:CLS
4170 END
5000 COLOR 13,1
5010 LOCATE 15,25
5020 PRINT "ERROR IN INSTALLING PCL830.BIN"
5030 COLOR 13,1
5040 STOP
5100 COLOR 13,1
5110 LOCATE 15,25
5120 PRINT "ERROR IN FUNCTION "+STR$(FUNC%)
5130 COLOR 4,1
5140 STOP
```